Visiting Faculty Research Program

2014 Research Topics

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Autonomy, C2, and Decision Support

Enabling Robust Autonomy

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Autonomy has been identified in the recent Air Force Technology Horizons report as one of the key technologies needed to support the USAF over the next 20 years. Many research challenges must be addressed before autonomous systems can be reliably deployed in practice, and AFRL/RI is broadly interested in addressing those challenges that occur as a result of the presence of massive amounts of data being available to an autonomous agent. Big Data problems can occur in autonomous systems as a result of being informed by many sensors or by attempting to leverage previously gathered information to better adapt to future situations, as well as from a variety of other causes. Generally, AFRL/RI is interested in topics from the knowledge discovery from data and machine learning fields that can help scale autonomous agents to real-world problems, or make complex problems more tractable for agents. Specific topics include:

- Efficient problem representation - Reinforcement learning (RL) is seen as a key enabling technology of autonomy. One obstacle in the path of robust autonomy is the difficulty that RL has in scaling up to environments described by many variables. It may be the case that these variables do not characterize the most efficient space to learn in due to redundant or irrelevant information captured by the given variables. For this reason, we are interested in novel techniques that can reduce the effective size of a problem, such as feature selection or extraction, state abstraction or aggregation, and problem decomposition.
- Anticipating versus Reacting - Conditions in real-world environments are dynamic - threats emerge and may be neutralized, capabilities appear without warning, etc. - and robust autonomous agents must be able to act appropriately despite these changing conditions. To this end, we are interested in identifying events which signal that a change must be made in agent behavior by mining past data from a variety of sources. This capability would allow agents to learn to anticipate and plan for scenario altering events rather than reacting to them after they have already occurred.
- Safe Exploration - In machine learning contexts (e.g. RL) there is a trade-off between an autonomous agent exploiting what it has already learned versus exploring the environment with the expectation of improving its behavior. Exploration can be dangerous, however, since exploring in a critical region of the environment can lead to a catastrophic failure of the agent. We are interested in developing techniques that can

guarantee safe exploration in real-world scenarios, or efficient exploration policies that minimize the chances of a catastrophic failure while still allowing an agent to improve towards optimal behavior.

Modeling and Simulating Integrated Command and Control Systems

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Military command and control systems are complex, systems of systems that combine numerous applications programs and cross multiple networks, computing systems, and databases. As the Air Force moves toward integrating command and control functions into an integrated command and control system, modeling and simulation offers one approach for exploring new and existing system architectures and system performance. Additionally, modeling and simulation can form the basis for developing methods for exercising and experimenting with integrated command and control systems. Research areas of interest within this topic include:

- Methods for developing enterprise models of integrated command and control systems that may include new and legacy components.
- Development of integrated command and control system models, such as Unified Modeling Language (UML) models, to identify information exchange requirements and characterize general system performance.
- Development of integrated command and control system measures of performance and measures of effectiveness (MOPs/MOEs) that can be obtained via simulation.
- Development of integrated command and control system methods to determine Mission Critical Systems on the network.
- Methods for rapidly developing simulation scenarios for exercising command and control system models.

Context Sensitive Information Visualization to Enhance Situational Awareness

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Situational awareness is the "fabric" for collaboration and team synchronization in military operations. To be most enabling, its content and the presentation of that content must adapt to the information needs of individual team members, their tasks, and their current situation (context). It must seamlessly bridge the strategic, operational and tactical levels of military operations supporting decisions and actions at all levels. We are looking for researchers to explore the science of adaptive, context sensitive visualization of complex data rich environments, to support

team self-synchronization/situation awareness and develop the underlying science needed to engineer future military systems.

Research areas of interest within this topic include:

- Hardware accelerated vector product visualization.
- OpenGL shader abstractions to support reuse
- Network status information compiled into useful metrics.
- Visualization of complex information systems.
- Multi-threaded parallel algorithms for network visualization and layout
- Various techniques for decluttering data and the visualization of that decluttered data.
- Appropriate visualization abstractions that work over WebGL/Javascript or other browser enabled capabilities and langauges
- Composable visualization system interfaces that reduce the amount of user end programming, but still offer rich expressivity

Advanced Information Visualization and Human Computer Interaction

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In order to provide airmen with an information environment that is dynamic and tailorable based on information needs, we are developing advanced visualizations techniques and interactive displays. Some of our technical challenges include fast access to voluminous dynamic data; high fidelity representations; effective visual interfaces for analyzing large data sets; evaluation metrics for visualization success; effective interaction techniques; integrating large high-resolution displays into a seamless computing environment; and perceptually valid ways of presenting information on a large display. Researchers will investigate effective use of visualization hardware and software. Specific domains include: man machine models; large screen and handheld multi-touch displays; multi-modal interaction; continuous speech; natural language dialogue; eye tracking and gesture interpretation; intelligent interfaces and adaptive mediators; untethered pointing and interaction devices; 3D graphics and visualization; synthetic environments and virtual world C2 applications; display tiling and high resolution media; collaborative interaction and decision making; integrated C2 situational awareness across air, space, and cyber domains; and mission planning and rehearsal.

Multi-agent Planning for Autonomous Support in Command and Control

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In an effort to support the Air Force's mission to develop robust autonomous Command and Control systems, we are interested in furthering the identification of problems, and development of solutions, in multi-agent planning. Multi-agent planning involves the development and coordination of individual plans by a collection of distributed agents to accomplish assigned goals. We are interested in multi-agent planning solutions in resource-constrained environments (processing power and communication restrictions) with time-sensitive goals. We have identified three broad topic areas of interest we would like to investigate in attempt to provide a multi-agent planning capability for autonomous C2.

- *Plan de-confliction* – The initial phases of planning are the most important part of the planning process. Local planning by distributed agents may be efficient, but often leads to the need for plan conflict resolution and negotiation once partial plans are aggregated. Finding effective ways to reduce the occurrence of initial plan conflicts as well as minimize the amount of time required to de-conflict a set of partial plans is critical to time sensitive mission requirements. We are interested in multi-agent solutions to initial (partial) plan selection, fast plan de-confliction, and plan merging for large plan assembly.
- *Plan deviation recognition and repair* – Once a plan is generated and conflicts are resolved, there exists the potential for a plan to begin to deviate from its initially intended goal(s). Given that the intent of a plan is common knowledge amongst all agents, quick recognition of a plan off course and the generation of potential plan repair options will ensure that even if/when a plan begins to deviate; there will be online methods of providing correction that will not require a complete re-planning phase. We are particularly interested in methods for the local identification of plan deviation and development of local plan repair.
- *Fast plan generation through Swarm intelligence* – As time is a critical factor in many planning situations, we are interested in alternative methods for generating quick planning solutions that can satisfy the intent of the plan, even if they are not optimal. As multi-agent planning is inherently distributed and potentially large-scale, biologically-inspired swarm intelligence could play a role in meeting the demands of resource constrained, time sensitive planning and tasking. Simple, efficient, actions coordinated across many individuals have the potential to produce complex, goal-oriented, group behaviors using reduced processing power and less time. Exploring such systems to determine their adaptability and applicability to military planning could lead to the development of new planning paradigms for autonomous systems supporting Command and Control (C2).

Challenges in Massive Point Cloud Visualization and Analysis

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Historical LiDAR collection efforts have already generated massive point cloud datasets, and new efforts are collecting as much as 1 Terabyte of data per hour of flight. Currently available applications/toolkits for processing point cloud data have several limitations which prohibit scalability, timely dissemination and analysis. The focus of this research is on techniques that could be used on raw data during collection (or very soon after), enabling clients to gain access in near real-time to data for analysis or to improve situation awareness. Research efforts include the design of server based techniques to minimize client systems processing and storage requirements, and development of visualization capabilities usable by client applications. Research areas of interest include:

- Visualization of point cloud data using level of detail, or decluttering algorithms
- Techniques for fusion of supplementary geospatial data sources with point cloud data
- Techniques for classifying 3D geometric patterns within point cloud data
- Methods for point cloud change detection
- Automation techniques to assist in 3D model generation from point cloud data

Mission Driven Enterprise to Tactical Information Sharing

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Forward deployed sensors, communication, and processing resources increase footprint, segregate data, decrease agility, slow the speed of command, and hamper synchronized operations. Required is the capability to dynamically discover information assets and utilize them to disseminate information across globally distributed federations of consumers spread across both forward-deployed tactical data links and backbone enterprise networks. The challenges of securely discovering, connecting to, and coordinating interactions between federation members and transient information assets resident on intermittent, low bandwidth networks need to be addressed. Mission prioritized information sharing over large-scale, distributed, heterogeneous networks for shared situational awareness is non-trivial. The problem space requires investigation, potential solutions and technologies need to be identified, and technical approaches need to be articulated which will lead to capabilities that enable forward deployed personnel to reach back to enterprise information assets, and allow rear deployed operators the reciprocal opportunity to reach forward to tactical assets that can address their information needs.

Network Defense through Dynamic Attack Surfaces

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Every network-facing computer system presents exploitable vulnerabilities. Remote method calls, communications channels, and persistent data items all present avenues for attackers to infiltrate the computer system with malware and exfiltrate sensitive data back to the attacker. Collectively, these attack vectors represent the "attack surface" available to outside (and inside) attackers. For most systems, the attack surface is static, changing very little or not at all over time. Consequently, an attacker is at liberty to analyze the target system at leisure and launch an attack at the time when the probability of success is highest.

This research seeks to mitigate this one-sided advantage by exploring the area of "attack surface shifting". If the attack surface of a system can evolve over time in a (pseudo) unpredictable manner, then an attacker will be forced to evaluate the attack surface in a much shorter time frame, reducing the attacker's advantage. This research addresses two areas; first, it investigates Attack Surface Quantification, analyzing and measuring the attack surfaces of existing computer systems. Second, it examines the application of Moving Target Defenses (MTDs), which enhance network security by morphing a system's attack surface over time.

Connectivity and Dissemination

Authentication in Tactical Airborne Networks

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Future airborne networks may consist of segments employing persistent, high bandwidth links (backbone) and much more dynamic, lower bandwidth links and nodes possibly operating in ad hoc networks. Some nodes will be entering/leaving the network frequently. Techniques for the rapid and reliable authentication of these users need to be developed to allow valid users easy access to the network and its information while keeping out unauthorized users and attackers. Techniques and technologies such as PKI, Zero Knowledge, Identity-based Authentication/Encryption and others need to be examined to determine their applicability in an airborne networking environment.

Wireless Optical Communications

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Quantum communications research involves theoretical and experimental work from diverse fields such as physics, electrical and computer science and engineering, and from pure and applied mathematics. Objectives include investigations into integrating quantum data encryption with a QKD protocol, such as BB84, and characterizing its performance over a roughly 30 km free space stationary link.

Free Space Optical Communication Links: Laser beams propagating through the atmosphere are affected by turbulence. The resulting wave front distortions lead to performance degradation in the form of reduced signal power and increased bit-error-rates (BER), even in short links. Objectives include the development of the relationship between expected system performance and specific factors responsible for wave front distortions, which are typically linked to some weather variables, such as the air temperature, pressure, wind speed, etc.

Keywords applicable to these studies are: quantum cryptography, free space laser propagation, Coherent state quantum data encryption, laser beam propagation through turbulent media, integration of quantum communications system with pointing, acquisition, and control system.

Airborne Networking and Communications Links

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This research effort focuses on the examination of enabling techniques supporting potential and future highly mobile Airborne Networking and Communications Link capabilities and high-data-rate requirements as well as the exploration of research challenges therein. Special consideration will be given to topics that address the potential impact of cross-layer design and optimization among the physical, data link, and networking layers, to support heterogeneous information flows and differentiated quality of service over wireless networks including, but not limited to:

- Physical and MAC layer design considerations for efficient networking of airborne, terrestrial, and space platforms;
- Methods by which nodes will communicate across dynamic heterogeneous sub-networks with rapidly changing topologies and signaling environments, e.g., friendly/hostile links/nodes entering/leaving the grid;
- Techniques to optimize the use of limited physical resources under rigorous Quality of Service
- (QoS) and data prioritization constraints;
- Mechanisms to handle the security and information assurance problems associated with using new high-bandwidth, high-quality, communications links; and
- Antenna designs and advanced coding for improved performance on airborne platforms.

Cognitive RF Spectrum Mutability

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When considering operations across terrestrial, aerial, and space domains, effective use of the limited Electromagnetic Spectrum (EMS) for a multitude of purposes is critical. The combined pressures of increasing demand for services and less available bandwidth for all make it imperative to develop capabilities for more integrated, flexible and efficient use of available spectrum for all functions (communications, radar, sensors, electronic warfare, etc.) across all domains (terrestrial, aerial, and space). In recognition of the need for affordable, multi-functional software-defined radios with spectrum agility and survivability in contested environments, this research effort seeks lightweight Next-Generation Software Defined Radio (SDR++) architectures and advanced waveform components for affordable solutions based on COTS and non-development items (NDI), relevant operational security, and appropriate trades in levels of software & hardware roots-of-trust. This will create an innovative high-performance flexible radio platform developed to explore the use of next-gen cognitive, smart-radio concepts for advanced connectivity needs across heterogeneous waveform standards and multiple EMS use-cases; while meeting tighter cost budgets and shorter time-to-fielding. The technology developments will support global connectivity and interoperability via multi-frequency/band/waveform reprogrammable radios for networked, multi-node aerial layer connectivity & spectrum mutability, providing system composability and engineered resilience.

Multi-User Detection for Random Access in Tactical Airborne Networks

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Existing access techniques in wireless systems are inefficient for large numbers of geographically spaced mobile users. Standard access techniques such Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), or Carrier Sense Multiple Access (CSMA) have limitations that reduce the effective utilization of the wireless data channels. Multi-User Detection (MUD) techniques may allow users to randomly access the channels and receive and detect multiple users through advanced detection and feedback loops in the receiver signal processing. These techniques need to be explored and developed further to evaluate the applicability and effectiveness in tactical airborne networks.

Malicious Behavior Detection for High Risk Data Types

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The Air Force relies on digital information brought in from allies, the open internet, and known adversaries in its day-to-day operations across the breadth of its operations. It is also known that modern antivirus products are unable to provide coverage against a sufficiently broad spectrum of malicious content. Given these two facts, it behooves the Air Force to develop novel approaches to assure its information as well as its information handling assets against malicious behaviors of data. In order to do this in the short term, researching how to leverage existing capabilities in novel ways may provide benefits faster than a traditional development cycle. The objective of this topic is to research reliably measurable differences between malicious and benign operations or sets of operations within commercial operating systems and hardware. This explicitly is not looking at the binary or source code, but rather the resultant operations of the source's actions within an appropriate commercial operating system & hardware infrastructure. Once there is one or more such measurable differences, create a proof of concept capability that is able to detect malicious executable content based upon detection of these malicious operations. The research is expected to be able to detect (and thus defeat) polymorphic transformations of existing malicious code and at least some potential zero day attacks.

Situational Awareness and Resiliency in Cross Domain Security Systems

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Cross-domain guard systems are a key component within any cross domain information sharing capability. Due to the guard's gatekeeper role between domains, it is a primary target for cyber attack from a low-side network trying to gain high-side access, or malware on the high-side trying to exfiltrate data to the low-side. Historically these systems have been designed as standalone units connecting the various security domains, but with separate management and reporting channels. They have little visibility of the status of their connected networks and the connected networks have little visibility on the status of them. Resiliency is an important trend in designing systems with regard to cyber defense. Simply put, resilience is the ability to provide and maintain an acceptable level of service in the face of faults and challenges to normal operation. Resilience is related to survivability, which builds on the disciplines of security, fault tolerance, safety, reliability, and performance. The approach assumes systems will be compromised to some extent and implements design strategies and techniques that support a balanced combination of protections, detections, and adaptive technical and operational responses that dynamically evolve in response to current and future cyber events. One important aspect of achieving resilient systems is to have good situational awareness of the environment and adapt to changes within that environment. This topic aims to view a cross-domain guard system as a key part of designing a resilient Multi-Level Security (MLS) system. Formalize techniques for collecting situational awareness information for the various connected security domains, sharing this information securely, and acting on this information based on policy in a

specific guard implementation agnostic fashion. Research should examine the current state-of-the-art of malware sensing and reporting in a closed systems environment, guard status reporting, guard management infrastructures, and applicable resiliency techniques (Protect/Deter, Detect/Monitor, etc.). The expected outcome of this effort is a new guard architecture, or an extension to an existing guard architecture where the guard is capable of acquiring sensor information from the various security domains that it is connected to, and increasing / decreasing its security posture appropriately based upon what it can detect.

Mobile Android Multi-Biometric Acquisition

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In order to minimize costs, increase accessibility of information and lessen the equipment burden on operators, several entities within the military, federal and municipal levels of government are finding it necessary to increase the functionality of their mobile devices. The Security-Enhanced Android operating system (SE-Android) has become the mobile OS of choice for secure cellular communications. Also, because information needs to be shared with various entities, security of those devices has become paramount. It is crucial that all available sensors on these devices be leveraged not only to identify the legitimate user, but also to gather as many biometric attributes as possible for analysis of target attributes, and mission execution. Mobile and tactical cross-domain devices such as phones and tablets can use their myriad sensors produce numerous data sets (imagery, audio, location, etc.) which may be useful in a number of scenarios. One such scenario is properly exploiting these data sets to provide a rich set of biometric data. Current applications and solutions often rely on gathering only a single biometric (fingerprint, iris/retinal, voice, etc.) while ignoring others that the device is capable of gathering. Researching and demonstrating the benefits of multiple biometric attributes to assure identity of the operator in realistic environments (smoke, noise, dirt, etc) may add non-trivial benefits to the security and trustworthy utilization of these devices. Other factors to consider during this research are battery usage, potential privacy concerns, reducing or (ideally eliminating) any external devices, and accuracy of various biometric authentication capabilities when implemented through these commercially available phones and/or tablets.

Secure Tactical Remote Executable Application Monitor

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Mobile and tactical cross-domain application functionality and communication is limited by the lack of persistent and reliable network connections in the field. Devices such as phones, tablets, and their related sensors produce various data sets (imagery, SIGINT, GPS, etc.) which should be shared and analyzed regardless of the quality and reliability of the backbone network connection. These devices need to function correctly for the warfighter in clandestine and rugged environments, without the need for constant reliable network connections. This is an inherent

weakness of cloud technology as it stands, especially when critical mobile applications are based in the cloud. While some technologies are being built to interface GOTS devices physically with existing networks, more development needs to be done. As such, research should be undertaken to enable these mobile devices (phones, tablets, etc) to recognize and operate on any available network in real time while reacting appropriately to the degree of connectivity these networks make available without excessively impacting the performance of commercial and GOTS applications. The scope of the research includes DIL (Disrupted, Intermittent, Latent) network conditions existing for periods of seconds to weeks with minimal impact to the operator. The ultimate goal would be to allow mobile devices to consistently operate regardless of their physical and networking environments. Note that this includes potentially utilizing more than one concurrent connection across multiple levels of classification and/or degrees of trust. This may require sending data at lower levels of classification over higher-level networks or vice versa, and may well induce different levels of sensitivity and/or classification of various sensors available to the device.

Semantics SOA

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Semantic SOA aims to formalize the architectural style and structure of service orientation through the use of formal modeling methods and techniques. Semantic technologies can be used to contextualize information in relation to consumers and prioritize its delivery. Semantically expressed service contracts and consumer profiles can also be used to dynamically discover and connect service providers with the clients that need them. Semantic models of relationships between concepts can be used to store relations in the information space for brokering and management purposes. Logic-based analysis techniques can be used to identify potential relationships between published information artifacts in order to build new and refine existing relationship models. Also of interest are semantic techniques to enhance the characterization of information models, facilitate shared updateable knowledge objects, and enable semantic query and subscription fulfillment.

Reactive Service Migration

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Reactive service migration involves service fault detection and fail-over mechanisms, information service workload migration strategies to relieve overloaded network resources, and pre-positioning of information and services by recognizing the usage patterns of information consumers to anticipate their needs ahead of time. Reactive service migration fail-over mechanisms might make use of workflow compensation, service redundancy, or other exception handling techniques. Workload migration may involve the use of load balancing techniques to achieve optimal resource utilization, maximize throughput, minimize response time, and avoid

overload. Pre-positioning of information and services might require the tracking and detection of events or changes in state which indicate an impending user need. In all cases, reactive service migration is concerned with optimizing the quality and availability of information management system services.

Enhanced Information Streaming

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Enhanced information steaming deals with techniques to annotate and otherwise characterize the content of steaming data in order to enrich our ability to interact with the data in ways that go beyond the frames and timelines that current video interfaces impose upon the user. Although frames and timelines are useful notions, they are less well suited for other types of interactions with video. In many cases, users are likely to be more interested such things as motion, action, character, and theme. For example, finding a moment in a video in which an object is in a particular place may be of interest, or the goal might be to compose a still image from multiple moments in a video. Although it is possible to compute object boundaries and to track object motion, typically this information is not captured in a manageable way, nor do present interfaces utilize this information for user interaction. Of interest are ways to embed glyphs and graphics into steaming media (such as descriptive labels, illustrative sketches, path arrows indicating motion, etc.), associating metadata with the indexed content of streaming data, and making this additional information available to consumers for managing the playback and use of streaming information in ways that add value based on specific user needs.

Causal Information Retrieval

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Standard Information Retrieval (IR) models use document and query representations to satisfy users' information needs. Boolean and vector space models match queries and documents using formally defined, but semantically imprecise, calculation of index terms. Given only the query representation, the system is unsure of the information need. Given a query "causes of inflation," for example, neither the query nor the document representation of standard IR models communicate to the system the need to assign higher weights to the most likely causes of inflation, which in this case a human would see as the most probable information need of the query. "Can a probabilistic causal model format be used to communicate or better define information needs of both the document and query representations?"

Autonomous Decision Making for Policy Enforcement

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The biggest threat to mission assurance is the lack of sharing of critical information in a timely and accurate manner within the cross-domain environment. This research will contribute to science of privacy, trust, and security in data dissemination among security domains. This effort requires a fundamental paradigm for decentralized information sharing to overcome existing hurdles in collaboration while considering privacy, integrity, and trust. Research requires integrating research in database systems, quality of service (QoS), privacy, trust, and contextual/situational awareness. Research also involves the discovery, propagation, and aggregation of information shared by multiple participants across domains under varying situations and contexts. The system must adapt to the type, extent, duration, and timing of multiple attacks/failures. Intellectual contributions should include the development of algorithms for proactive dispersion of information, situational-aware paradigm, integrity checks and violator identification methods, information adaptability, and active bundles.

Tasks:

- Provide sharing of critical information using the science of trust, privacy, and security in data dissemination among security domains
- Design algorithms that evaluate the privacy loss due to disclosure of information to gain trust.
- Develop privacy metrics using information theoretic approaches.
- Investigate various privacy violator models and user behaviors to be used as benchmarks for testing and evaluation.

Data Aggregation & Attestation

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A classic concern with automated data handling is the data aggregation issue, also referred to as the ‘sources and methods' problem. That is, a document made up of multiple pieces of information may end up with a final classification higher than any of its constituent parts. Finding methods to assure this does not happen within automated, adaptable services is a major challenge. Further, finding automated or automatable methods to validate and attest that it has not occurred increase the level of difficulty.

Dynamic Resource Allocation in Airborne Networks

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From the Air Force perspective, a new research and development paradigm supporting dynamic airborne networking parameter selection is of paramount importance to the next-generation warfighter. Constraints related to platform velocity, rapidly-changing topologies, power, bandwidth, latency, security and covertness must be considered. By developing a dynamically reconfigurable network communications fabric that allocates and manages communications system resources, airborne networks can better satisfy and assure multiple, often conflicting, mission-dependent design constraints. Special consideration will be given to topics that address cross-layer optimization methods that focus on improving the performance at the application layer (i.e. video or audio) and/or examine the spectral utilization problem in cognitive networks.

Combinatorial Designs for Key Distribution

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Key pre-distribution schemes are required for certain kinds of wireless networks. One approach is to utilize combinatorial design theory as a means of developing a set system of keys with a specified amount of overlap. These sets of keys are then deployed with the nodes in the wireless network. Thus the robustness and connectivity of the network depend solely on the key pre-distribution scheme employed. Combinatorial designs provide a method for addressing these concerns in a scalable manner.

Cyber Science and Technology

Cyber Defense Research

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Cyber Defense is concerned with the protection and preservation of critical information infrastructures in order to ensure the United States' dependency on cyberspace remains beneficial and does not turn a technological advantage into a vulnerability.

This technology area seeks to: 1) protect our own information space through assurance, agility, denial, deception, and deterrence; 2) enable our system to automatically survive attacks through an innate ability to deal with unanticipated states and environments; 3) provide the means to identify, understand, attribute and localize vulnerabilities before they are exploited, and attacks as they occur; and 4) recover and reconstitute systems, data, and information states rapidly to ensure continuity of operations.

Fundamental research areas of interest within this topic include:

- Methods for mission mapping and dependency analysis within complex systems; going beyond computer and network assurance to mission assurance.
- Design of trustable systems composed of both trusted and untrusted hardware and software; study of virtualization and trusted platforms
- Algorithms and innate mechanisms that enable systems to automatically continue correct operation when presented with unanticipated input or in the face of an undetected bug or vulnerability.
- Techniques that can disrupt an attack during its early stages (reconnaissance, planning, and testing), such as polymorphism, agility, and randomization, at all layers of networking and computer architectures, to reduce the attackers' understanding of our systems and their ability to launch attacks, while maintaining our own situation awareness: “moving target defenses.”
- The ability of information systems to “fight through” attacks, without operator intervention, in a contested environment characterized by “zero day” attacks.
- Examination of assumptions, mechanisms, and implementations of security features that may be adequate for wired networks and devices but provide opportunities for attacks on wireless and mobile systems.
- Theories of complex systems describing interactions of large systems and systems of systems that lead to better understanding of their emergent behaviors during attack and reconstitution; epidemiological models that may be used to predict system responses to Internet worms and coordinated attacks as well as analyses of self-healing and self-restoring systems.

Development of new cryptographic techniques is not of interest under this research opportunity.

Achieving Survivability in Cyberspace

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We begin by noting that unlike air or space, cyberspace differs in a fundamental way: air and space are natural settings, but cyber is man-made. As a made-made entity, cyberspace is composed of networking and information resources – and is therefore subject to human control. Because of this distinction, the human ability to create and sustain cyber-level linkages can become a venue for malice.

Defense of cyberspace is challenging. The seemingly endless breadth of cyberspace coupled with the technological depth of its composition can divide defensive approaches to be either overarching or highly specific. In order to abstract away details for the purpose of tractability, overarching approaches can suffer because simplistic models for threats, vulnerabilities, and exploits tend to yield defenses that are too optimistic. Approaches that deal with specific threats, vulnerabilities and exploits may be more credible but can quickly lose their meaningfulness as technology changes. Whether approaches are near-or-far term, we see that two underlying attributes remain essential: the ability to survive and the ability to fight through.

The compendium of survival and fight through has, for us, spurred the need for this topic on survivability in cyberspace. Our justification for treating survival and fight-through as inseparable is: although cyberspace's apparent vastness seems to convey a limitless supply of information and network-related resources, the actual amount of these resources under any single genuine entity's control is typically very limited. However, an attacker's aim to overtake resources may not be easily bounded. Thus, driving our goal's dual survive-and-fight-through make-up is that while the part of cyberspace under single, genuine control is limited, for that same part of cyberspace an adversary's aim is to maximize control. This dictates that survive and fight-through remain joined. Considered separately, accumulated loss of resources to the adversary will eventually undermine the ability to survive or the ability to fight through – but that is not so for both. That is, surviving an attack by sustaining its damage and fighting through that attack- again and again if necessary - with those remaining resources under the defender's control allow the system to emerge, and remain, undefeated.

This topic is aimed at covering the breadth of survivability of cyberspace as outline above. Ideas that deal with solving some portion of the overall cyberspace survivability goal are welcome. A potential approach is to transform concepts from the field of fault tolerance to cyberspace survivability. Visiting faculty will perform in-house research as part of the Cyber Science branch's in-house research effort "Fault Tolerance for Fight Through.

Information Theoretic Secure Cloud Computing and Cloud Auditing

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Cloud computing represents one of the most significant shifts in information technology. However, there are persistent concerns about cloud computing security risks. This research aims to develop secure cloud computing and cloud auditing technologies in order to reduce cloud security vulnerabilities and increase the performance of cloud computing in hostile network environment. Areas of interest include information theoretic security/secure computing applications in DoD Public Key Infrastructure (PKI) environment, secure data management and sharing, efficient metadata management, web 2.0/web 3.0 technology, compression, massive real-time stream data analysis and transmission, Quality of Service mechanism, router-based traffic control, visualization, Wireshark enhancement, cyber threats analysis, automatic cloud auditing, and other cloud security applications including Android Smartphone security.

Market-Based and Game Theoretic Methods for Resource Allocation in the Cloud

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Information systems are continually expanding as evidenced by the doubling of Internet connections every year. Similar growth is exhibited by information systems in defense. The Air Force's mission to fly and fight in Air, Space, and Cyberspace involve the technologies to provide information to the warrior anywhere, anytime, and for any mission. This far-reaching enterprise will necessarily span multiple networks and computing domains that include those that are commercial and exclusively military. As a result, many users with different goals and priorities vie for the communication and computing resources. Managing this vast system to ensure dependable operation that maintains users' quality of service levels has led researchers to propose computational markets as a means for controlling the allocation of system resources. Economics has always been a factor in engineering. Because it is also the study of resource allocation problems, economics is sought to provide the answer to managing large-scale information systems. By introducing software agents, pricing mechanisms, and game-theoretic mechanisms, the computational economy will strive to exhibit the same phenomena as a real one; it will admit arbitrary scale, heterogeneity of resources, decentralized asynchronous operation, and tolerance of localized failures. These derived benefits are compelling and recent advances in cloud computing have created opportunities for the serious contemplation of building computational markets.

Application of Game Theory and Mechanism Design to Cyber Security

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Cyber attacks pose a significant danger to our economic prosperity and national security whereas cyber security seeks to solidify a scientific basis. Cyber security is a challenging problem because of the interconnection of heterogeneous systems and the scale and complexity of cyberspace. This research opportunity is interested in theoretical models that can broaden the scientific foundations of cyber security and develop automated algorithms for making optimum decisions relevant to cyber security. Current approaches to cyber security that overly rely on heuristics have been demonstrated to have only limited success. Theoretical constructs or mathematical abstractions provide a rigorous scientific basis for cyber security because they allow for reasoning quantitatively about cyber attacks.

Cyber security can mathematically be modeled as a conflict between two types of agents: the attackers and the defenders. An attacker attempts to breach the system's security while the defenders protect the system. In this strategic interaction, each agent's action affects the goals and behaviors of others. Game theory provides a rich mathematical tool to analyze conflict in strategic interaction and thereby gain a deep understanding of cyber security issues. The Nash equilibrium analysis of the security games allows the defender to allocate cyber security resources, understand how to prioritize cyber defense activities, evaluate the potential security risks, and reliably predict the attacker's behavior.

Securing cyberspace needs innovative game theoretic models that consider practical scenarios such as: incomplete information, imperfect information, repeated interaction and imperfect monitoring. Moreover, additional challenges such as node mobility, situation awareness, and computational complexity are critical to the success of wireless network security. Furthermore, for making decisions on security investments, special attention should be given to the accurate value-added quantification of network security. New computing paradigms, such as cloud computing, should also be investigated for security investments.

We also explore novel security protocols that are developed using a mechanism design principle. Mechanism design can be applied to cyber security by designing strategy-proof security protocols or developing systems that are resilient to cyber attacks. A network defender can use mechanism design to implement security policies or rules that channel the attackers toward behaviors that are defensible (*i.e.*, the desired equilibrium for the defender).

Processing and Exploitation

Motion Imagery (or Video) Processing and Exploitation

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Motion Imagery sources include everything from airborne collectors to YouTube. New and innovative technology is required to exploit and extract the relevant information content and manage the whole exploitation process. Visual processing is the focus, but leveraging all aspects of the data is of interest (e.g. audio and metadata) as well as using any additional correlating sources (e.g. reference imagery or coincident sensors). Both semi-automated and fully automated capabilities are of interest. Emphasis will be on overcoming or working around the current limit of computer vision to lead to a useful capability for an AF analyst. Sample topics of interest would be: biologically inspired techniques, scene classification, event detection, object detection and recognition, optimization techniques, Bayesian methods, geo-registration, indexing, etc.

Audio Processing

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The Audio Group in AFRL/RIGC is involved in all aspect of speech processing and is a unique combination of linguists, mathematicians, DSP engineers, software engineers, and intelligence operators. This combination of individuals allows us to tackle a wide spectrum of topics from basic research such as channel estimation, robust word recognition, language and dialect identification, and confidence measures to the challenging transitional aspects of real-time implementation, GUI design, and concepts of operations. The Audio Group also has significant thrusts in noise estimation and removal, speaker identification including open-set identification, keyword spotting, robust feature extraction, language translation, analysis of stressed speech, coding algorithms along with the consequences of the compressions schemes, watermarking, co-channel mitigation, and recognition of background events in audio recordings.

Communications Processing Techniques

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We view communications processing as the gathering and exploitation of technical information derived from communication signals. The communication processing we perform mainly deals with the exploitation of messages or voice information but excludes open radio and television

broadcasts. To perform exploitation, we need to develop advanced technologies to intercept, collect, locate and process communication signals in all parts of the spectrum. The objective is to maximize the information that can be extracted from this raw data. This information includes:

- Person or source of the communication
- Location of the transmitter
- Function of the transmitter
- Radio Frequency (RF) and other technical characteristics of the transmission
- Content of the transmission
- The recipient of the transmission

The end result is the development of automated processes to extract, analyze, correlate, sort and report information.
The technical challenges include: development of interference cancellation techniques/ multi-user detection (MUD) algorithms, beamforming techniques, hardware architecture and software methodologies, geolocation techniques and systems, and signal processing software. Research into developing unique and advanced methods to collect, process and exploit communication signals in high density rapidly changing environment is of great importance. The research is expected to be a combination of analytical and experimental analyses. Experimental aspects will be performed via simulations using an appropriate signal processing software tool, such as MATLAB.

Wireless Sensor Networks in Contested Environments

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Sensor networks are particularly versatile for a wide variety of estimation tasks. Due to the nature of communication in a shared wireless medium, these sensors must operate in the presence of other co-located networks which may have competing, conflicting, and even adversarial objectives. This effort focuses on the development of the fundamental mathematics necessary to analyze the behavior of networks in contested environments. Security for dynamically changing networks is of interest.

Research areas include but are not limited to optimization theory, information theory, detection/estimation theory, and game theory.

Development of new cryptographic techniques is not of interest under this research opportunity.

Anticipation

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Research in the areas relating to tools that support situation awareness and specifically anticipation of both adversarial and general populace actions/reactions is of interest. Such tools include the ability to combine lower level entities/events into groups and situations, the ability to assess these situations in current time (their impact) and the ability to project the current situation(s) to identify potential threats in our ability to perform our mission. In order to accomplish this, various disciplines from computer and cognitive sciences, artificial intelligence and operations research must be brought together. We seek new and interesting approaches in the following areas:

- Scalable/Robust Model Analysis and Pattern Matching Techniques for providing Situation/Group Recognition and Interpretation (to include such meta-data as uncertainty, severity and perishability)
- Stochastic Modeling Techniques and Sensitivity Analysis Techniques (DOE and DACE) for "large" scale hybrid (systems dynamics, agent-based, procedural, etc.) models
- Development of Situation Assessment Algorithms
- Development of Threat/Impact Assessment Algorithms
- Identification/Recognition of Adversary Intentions
- Identification of "key" differentiating events to support information requirements and collection
- Modeling human behaviors (individual and group) and the environment within which they exist to include such concepts as grievance, risk aversion and satisfaction/content.
- Metrics for Measuring the Performance and Effectiveness (MOE and MOPs) of Situation, Impact/Threat Assessment Techniques in supporting the analyst, operator and decision maker
- Visualization of Complex Relationships
- Verification and Validation of "complex" models
- Architecture/Frameworks that support Interactive Gaming Environments using the knowledge developed to aid Command & Control (C2) operators in Course of Action (COA) development

Advanced Object Fusion, Identification & Tracking

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A summer faculty researcher is needed to explore new methods of image/video exploitation in large volumes of images and video data. The goal is to characterize events, activities and scenarios in image data containing people (insurgents, for example), vehicles (suspicious), and weapons (Rocket Propelled Grenades – RPGs) immersed in terrain, or among buildings. These images can be readily found on the internet. The ultimate objective is to develop procedures that will go through several images and find all the ones that have a given attribute within them (for example, all these images contain RPGs). Methodologies must be developed in order to automatically determine the contents of the video. First algorithms to recognize objects and associate metadata to those objects are necessary in developing an understanding of imagery contents. Next, by summarizing the detailed characteristics of images and identifying kinematic patterns of those objects, one can develop a context behind object detection and tracking in a video. Further characterization of the objects can be added by querying databases for more detailed descriptions of the objects in the video. The focus will be on the actual video analysis, to assist the human in analyzing the video for patterns of life and normalcy pattern analysis. In addition to object recognition, there is a need to automate scene recognition and understanding. Possible areas of concentration include but are not limited to:

- Ground Truthing of image characteristics
- Discriminative scene understanding (with and without training)
- Space-time scene classification
- Scene categorization
- Annotation, segmentation of images
- Blur compensation (due to camera shake, for example) – this is a pre-processing step

Knowledge Discovery Metrics

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Research to clearly define performance evaluation metrics for Dynamic Network Analysis applications is of interest. Performance is the degree to which a system or component accomplishes its designated functions within given constraints, such as speed, accuracy, or memory usage. Having a solid suite of performance metrics would yield the advancement of network discovery tools by increasing the effectiveness, efficiency, and usability of analytical programs as well as reducing the amount of time and financial assets spent on their development. Within the intelligence community, there is a severe deficiency in a method or standard procedure to unambiguously evaluate the performance of network discovery applications.

Developing such a process and an initial understanding of these systems would provide a great benefit to the intelligence community.

Natural Language Processing for Text Analytic Applications

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Research in the area of Natural Language Processing to improve text analytic processes is of interest. This will involve examining the current state of the art and practice, consider the shortcomings to these approaches and consider new and novel approaches to address these shortcomings. Researchers will need to consider theories from outside the current area of research and provide methods for implementation and evaluation of performance of these proposed methods. This research would then be applied to improve processes for the following areas but not limited to:

- Text Extraction
- Semantic Role Labeling
- Text Classification
- Document Clustering
- Indexing and Search
- Sentiment Analysis
- Event Extraction
- Information Retrieval
- Multi-source Information Extraction
- Multi-lingual Processing of Text
- Machine Translation

Link & Group Understanding

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AFRL seeks innovative research in the area of link and group understanding, more commonly referred to as social or dynamic network analysis. More specifically, AFRL seeks automated or semi-automated procedures to infer from externally observed data the existence, topology, leadership, and other characteristics of covert social networks including but not limited to the discovery and understanding of unknown activities and associated trends/patterns/relationships. In addition, these techniques should move beyond the limitations of traditional approaches to

consider temporal dynamics and\or multi-modal networks and are most interesting when researched in the context of a variety intelligence sources and types and the challenges presented by "Big Data."

Foundations of Trusted Computing

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Research opportunities are available for the design, development and demonstration of foundations of trustworthy computing, including technology, components and methods supporting a wide range of requirements for improving the trustworthiness of computing systems via multiple trust anchors. Research supports security, reliability, privacy and usability leading to high levels of availability, dependability, confidentiality and manageability. Thrusts include hardware, middleware and software theories, methodologies, techniques and tools for trusted, correct-by-construction, composable software and system development. Specific areas of interest include: perpetual model validation (both of the system interacting with the environment and the model itself), trusted evolvability and reduced complexity of autonomous systems; effective trusted real-time multi-core exploitation; architectural security and trust; provably correct complex software and systems; composability and predictability of complex real-time systems; trustworthiness of open source software; scalable formal methods for verification and validation to prove trust in complex systems; novel methodologies and techniques which overcome the expense of current evidence generation/collection techniques for certification and accreditation; and a calculus of trust allowing trusted systems to be composed from untrusted components.

High Assurance Computing

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The objective of this topic is to investigate the necessary building blocks for high assurance computing environments (environments where compelling evidence is supplied to determine a high level of trustworthiness), including both the underlying hardware and software to support it. Areas of interest include, but are not limited to: (1) the problems and challenges with current processor designs for trustworthiness and their solutions; (2) the problems and challenges with current computer architectures for trustworthiness and solutions to them; (3) the Operating System level constructs, objects, and functions that must be provided to complement the hardware to enable a trustworthy computing base; (4) state of the art software-based assurance designs, methodologies or concepts which are better suited for implementation in hardware than software; (5) research and development for increasing the level of trustworthiness of integrated circuit designs, commodity integrated circuits and currently available systems as a whole; (6) research into and development of solutions to mitigate implications of state-of-the-art commercially available processor architectures (including multi-core, GPUs, FPGAs, etc.) and specially designed processor architectures on Separation Kernels and other secure micro-kernels

being developed by real-time operating system vendors for use in environments requiring high assurances; and (7) research and development supporting software, e.g. high assurance middleware technologies, to enhance system interoperability and capability to support cross domain solutions enabling delivery of trustworthy, superior and timely information.

Formal Methods for Complex Systems

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Formal methods are based on areas of mathematics that support reasoning about systems. They have been successful in supporting the design and analysis of systems of moderate complexity. Today's formal methods, however, cannot address the complexity of the computing infrastructure needed for our defense.

This area supports investigation on new powerful formal methods covering a range of activities throughout the lifecycle of a system: specification, design, modeling, and evolution. New mathematical notions are needed: to address the state-explosion problem, new powerful forms of abstraction, and composition. Furthermore, novel semantically sound integration of formal methods is also of interest. The goal is to develop tools that are based on rigorous mathematical notions, and provide useful, powerful, formal support in the development and evolution of complex systems.

Trusted Software-Intensive Systems Engineering

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Software is a prime enabler of complex weapons systems and command and control infrastructure and its fungible nature will be key to development of next generation adaptive systems. Yet, software is the most problematic element of large scale systems, dominated by unmet requirements and leading to cost and schedule overruns. As the complexity of today's system lies in greater than 10^5 requirements, greater than 10^7 lines of code, thousands of component interactions, greater than 30 year product life cycles and stringent certification standards, one of the great open challenge questions is how does one bring trust and adaption into the development, verification and validation of software intensive systems?

The objective of the trusted software-intensive systems engineering topic is to develop techniques, methodologies and tools to enable and migrate the analysis from execution (testing and monitoring) to design (correct-by-construction and formal/security specifications) and development (composition and auto-generation of artifacts). Areas of interest include: techniques to enable trust in model-based software engineering; model-based engineering for predictable software attributes; provably correct code generation; evidence-based software assurance; trusted software composability; and software comprehension

Many-Node Computing for Cognitive Operations

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The sea change in computing hardware architectures, away from faster cycle rates and towards processor parallelism, has expanded opportunities for development of large scale physical architectures that are optimized for specific operations. Porting of current cognitive computing paradigms onto systems composed of parallel mainstream processors will continue in the commercial world. What higher cognitive functionality could we achieve if we take better advantage of physical capabilities enabled by new multi-processor geometries?

Perception, object recognition and assignment to semantic categories are examples of lower level cognitive functions. Assignment of valence, creation of goals and planning are mid level functions. Self awareness and reflection are higher level processes that are so far beyond current cognitive systems that relatively little has been done to model the processes. Often, models assume higher cognitive processes will emerge, once the computing system reaches some level of speed / complexity. The problem is that the computational power required exceeded the reachable limit of single processor architectures and probably exceeds the limits of conventional parallel architectures. This topic seeks to enable mid and higher level cognitive function by creation of new physical architectures that address the computation demand in novel ways.

We are interested in developing models for the computational scale of the mid and higher functions and processor / memory node architectures that facilitate cognitive operations by configuring the physical architecture to closely resemble the functional cognitive architecture, e.g., where each node in a network represents and functions as a processor for a single semantic primitive. What new hierarchical architectures could we design for million node systems, where the individual nodes may be small ASPs, with very fast communication between nodes? A project of interest would combine both sides, new algorithms for higher level cognitive functions and new architectures to enable the computation in a realistic time frame. AFRL/RIT has projects on line to enable million node systems.

Nanocomputing

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Advances in nanoscience and technology show great promise in the bottom-up development of smaller, faster, and reduced power computing systems. Nanotechnology research in this group is focused on the development of crossbar computing architectures which utilize existing nanotechnologies including nanowires, coated nanoshells, memristors, and carbon nanotubes and are scalable to 100x100 arrays. We have a particular interest in the modeling and simulation of architectures that exploit the unique properties of these new and novel nanotechnologies. This includes development of nonlinear sub-circuit models that accurately represent sub-circuit

performance with subsequent CMOS integration. Also of interest are the use of nanoelectronics and thermal management techniques using nanotechnologies in 3D computer architectures.

High Performance Computing and Algorithmic Challenges/Solutions in CSE

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Computational science and engineering (CSE) is a multidisciplinary area based on the intersection of computing, sciences, and engineering. The role of computing in a scientific endeavor has changed significantly over the last several decades. It has grown from a tool to analyze experimental results to a vital component for simulation & modeling, experimental instrumentation, large scale experimentation and knowledge discovery. Nearly all facets of complex scientific discovery -- theoretical, experimental, analytic, synthetic and explorative -- involve some form of computation. Rapid advancement in computer architecture, increased sophistication sought by application scientists, steady growth in complex scientific principles sought to be incorporated. The ever increasing scale of required computations demand participation by the domain experts, computer scientists, instrumentation, experimental and operational engineers and the end users, more frequently throughout the design cycle. Such interactions facilitate a more balanced approach to design tradeoff when compared against domain partitioned design and integration of complex systems. Our challenge is to develop the necessary insights and identify the best practices to help foster and accelerate scientific discovery vital for developing affordable high performance war fighting systems in cost and on time with predictable measures of performance and precision -- using our resources: high performance computing systems, instruments, people and infrastructure. A candidate set of problems includes and is not limited to the following list: 1) challenging CSE problems in wide area persistent surveillance; activity analysis in complex multi-dimensional spatio-temporal data-sets; 2) advanced scientific image analysis and knowledge discovery techniques on scalable multi-core high-performance computing architectures; 3) high-performance focused scalable machine-learning algorithms in the context of anticipative computing; 4) software engineering, productivity enhancement tools to catalyze wide spread application of high performance large scale computing in experimental and explorative scientific studies; and, 5) any topic of relevance to Air Force mission involving application science, large scale computing, precision and performance metrics driven operational constraints.

Quantum Computing Theory and Simulation

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Quantum computing research involves interdisciplinary theoretical and experimental work from diverse fields such as physics, electrical and computer science, engineering and from pure and applied mathematics. Objectives of AFRL's Emerging Computing Technology Branch include the development of quantum algorithms with an emphasis on large scale scientific computing

and search/decision applications/optimization, implementations of quantum computational schemes with low error threshold rates, implementations of quantum error correction such as topological protection, and the simulation of quantum circuits/computers and quantum error correction schemes with an emphasis on modeling experiments. Topics of special interest include the cluster state quantum computing paradigm, quantum simulated annealing, the behavior of quantum information and entanglement under arbitrary motion of qubits, measures of quantum entanglement, and the distinction between quantum and classical information and its subsequent exploitation.

Compressive Sampling

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This topic addresses the theory and applications of compressive sampling. This includes:

- Development of a theoretical framework for compressive sampling. One promising direction is based in part on the study of nonconvex compressive sampling.
- Application of computational methods to advance the state-of-the-art in airborne networking. For example, the realization of rank deficient network coding is a recent application of compressive sampling technology to network coding.
- Application of compressive sampling to permit novel computational paradigms. Such paradigms show potential for a myriad of applications, including wireless parallel computers.

Quantum Information Processing

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The topic of Quantum Information Processing is to be focused on Computational Methods and Architectures. It has been well established that a computer based on quantum interference could offer significant increases in processing efficiency and speed over classical versions, and specific algorithms have been developed to demonstrate this in tasks of high potential interest such as data base searches, pattern recognition, and unconstrained optimization.

However the present experimental progress, lagging far behind the theoretical, is at the level of several gates or Q bits. The entangled photon approach to quantum gates including quantum gates, cluster states, and Linear Optical Quantum Computing will be experimentally pursued with particular attention to scalability issues. Experience with generation and detection of entangled photons is essential for this interaction, with parametric amplification a plus.

Theoretical advances will also be pursued with existing and custom quantum simulation software to model computational speedup, error correction and de-coherence effects. Algorithm

investigation will focus on hybrid approaches which simplify the physical realization constraints and specifically address tasks of potential military interest.

Optical Interconnects

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AFRL's Emerging Computing Technologies Branch offers research opportunities in the area of computer optical interconnects closely coupled in effective ways to processors and/or memories in order to decrease the latency associated with standard interconnects and intra-computer communication. Novel optical interconnect components, architectures, algorithms and subsystems are needed to perform inter-processor, processor to memory and memory to memory interconnects. This includes through open space for compact multiprocessor cores or through optical fibers and/or waveguide for processor to processor interconnects in computational clusters.

Our main area of interest is the design, modeling, and building of interconnect devices for advance high performance computing architectures with an emphasis on interconnects for quantum computing and the use of plasmonic techniques. Current research focuses on interconnects for quantum computing including switching of entangled photons for time-bin entanglement. With its ability to supply a very high field in a very small area, plasmonics is a very promising technique in the quest to make nanoscale optical interconnects components.

Quantum computing is currently searching for a way to make meaningful progress without requiring a single computer with a very large number of qubits. The idea of quantum cluster computing, which consists of interconnected modules each consisting of a more manageable smaller number of qubits is attractive for this reason. The qubits and quantum memory may be fashioned using dissimilar technologies and interconnecting such clusters will require pioneering work in the area of quantum interconnects. The communication abilities of optics as well as the ability of optics to determine the current state of many material systems makes optics a prime candidate for these quantum interconnects.

Neuromorphic Computing

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Neuromorphic computing shows great promise in the development of intelligent systems able to imitate natural neuro-biological processes such as reasoning and perception. This is achieved by artificially recreating the highly parallelized computing architecture of the mammalian brain. In particular, neuromorphic computers are suitable for applications in pattern recognition and optimization, i.e. target finding, automated data processing, intelligence analysis, etc. In order to achieve high levels of intelligence within systems, neuromorphic computing exploits the characteristic behavior of novel complex materials and structures with advanced processing

techniques to achieve very large scale integration with highly parallel neural architectures. This research effort will focus on mathematical models, computing architectures and computational applications to develop neuromorphic computing processors. Also of interest, is the development of neuromorphic computing architecture software emulation and hybrid VLSI CMOS architectures utilizing nano- scale technologies. Special emphasis will be placed on promising technologies and solutions to satisfy future Air Force needs employing intelligent systems to achieve the desired level of autonomy.

Advanced Computing Processors Information Management

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As the number of computing processors is increased for most applications, a situation is reached where processor information management becomes the bottleneck in scaling, and adding additional processors beyond these number results in a deleterious increase in processing time. Some examples that limit scalability include bus and switch contentions, memory contentions, and cache misses, all of which increase disproportionally as the number of processors increase. The objective of this topic is to investigate existing and/or to develop novel methods of processor information management for multiprocessor and many-processor computing architectures that will allow for increased scaling.

Managing Very Large Image Collections

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This research effort focuses on developing the mathematical tools and algorithms necessary for the management, processing, and analysis of very large geometric data collections. Example datasets of interest include aerial and terrestrial range data, multi-view stereo images, high-resolution video and unstructured images. . Special consideration will be given to topics that propose novel ways for exploiting massive geometric datasets for the efficient storage, representation, retrieval, and exploration of the information captured by the data which would not otherwise be possible in the small scale.

Research topics include, but are not limited to new techniques for 3D scene reconstruction, segmentation, object recognition, 3D and image-based modeling, classification and spatial reasoning as well as novel visualization methodologies. The applicant should have a strong research record in related areas such as geometry processing, computer vision, computer graphics, machine learning, and applied mathematics.

Complex Network Inference

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Recent advances in sensing technology have enabled the capture of dynamic heterogeneous network data. However, due to limited resources it is not practical to measure a complete snapshot of the system at any given time. This topic is focused on inferring the full system or a close approximation from a minimal set of measurements. Relevant areas of interest include matrix completion, low-rank modeling, online subspace tracking, classification, clustering, and ranking of single and multi-modal data, all in the context of active learning and sampling of very large and dynamic datasets. Applications areas of interest include, but are not limited to communication, social, and computational network analysis, system monitoring, anomaly detection, and video processing. Also of interest are topological methods such as robust geometric inference, statistical topological data analysis, and computational homology and persistence. Candidates should have a strong research record in these areas.

Processing Exploitation and Dissemination of Video

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We are facing a steady growth in ubiquity and diversity of video data in addition to an explosive growth in volume of data. Both the latitude of images that can be sensed, access to harvestable opportunistic data, crowd sourced data, and archived images add a new dimension to the scope and precision of extractable information. This unprecedented growth offers ability to mine information that may be of critical import to various tasks we undertake. Existing methods on video analysis are not fully integrated to exploit the potential value and impact of wide spread, sparse, and piece-wise dense multi-modal data sets with imprecise meta-data and loosely coupled links to unreliable and often undependable related information. Various techniques ranging from motion analysis, location aware techniques, context and content based processing, storage, dissemination techniques, scalability and performance oriented algorithm development techniques, and highly-scalable machine learning techniques are of interest. These include, classic video processing techniques, emergent compressive sensing frameworks, wide-area motion imagery, high-definition location-tagged imagery, content based image retrieval, context based performance improvements, and embedding and exploitation of higher dimensional manifolds, and innovative machine learning algorithms such as support vector machines, share-boost etc. Although we are looking for fundamental works in pixels to perception chain, innovative

methods to address performance barriers in mapping new and established insights on to a data to decision processing chain is of equal importance. Algorithm development, prototyping and bench-marking of emergent and established algorithms for capturing, characterizing, indexing, archiving extractable information from video, including such metrics on precision, performance, scalability and versatility are within the scope of this thrust. Importance will be given to context and content awareness, performance, versatility, scalability, affordable high-performance and embedded- computing focused research.

Event Detection and Predictive Assessment in Near-real Time Complex Systems

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Making best use of multi-point observations and sensor information for event detection and predictive assessment in complex, near real time systems is a challenge which presents itself in many military domains. The first step in tackling these challenges is to analyze and understand the data. Depending on the algorithm used to detect an anomalous event, the nature and extent of variable correlations must be understood. This research will consider methods to quantify the strength of the correlations of input variables to output variables and develop techniques to account for lag times in the data itself. This is no easy task since sensor readings and operator logs are sometimes inconsistent and/or unreliable, some catastrophic failures can be almost impossible to predict, and time lags and leads in real world systems may vary from one day to the next. After detecting where the strongest correlations exist, one must choose a model which can best assess the current conditions and then predict the possible outcomes that could occur for a number of possible scenarios. Scientific issues of interest include, but are not limited to (1) advanced statistical methods to determine dependencies between senor inputs and the combined effect of multiple-sensors (2) adaptive correlation analysis techniques which will evolve to discover new dependencies in time as conditions change (3) adaptive pattern matching methods to take correlated sensor inputs and characterize normalcy and anomalous conditions.

Interleaving Acquisition and Processing of Geometric Data

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3D geometric data is becoming highly pervasive, both in terms of the acquisition and the analysis of such data. In constrained environments, however, the resources available for acquisition are limited. Moreover, the resulting geometry may be highly imperfect in terms of noise and completeness, necessitating new techniques for analysis.

This research effort focuses on new techniques for the acquisition of 3D geometric data under limited resources, and the analysis of such data. Of particular interest is the interleaving of acquisition and analysis, where an understanding of the environment drives the acquisition

process. Topics for geometry acquisition include, but are not limited to: multi-view stereo, photometric stereo, structured lighting, shape from image collections, surround methods for full environment acquisition, as well as the potential fusion of these and other modalities. Topics for geometry processing include, but are not limited to: surface reconstruction, registration, segmentation, scene summarization, large scale and out-of-core management of geometric data, as well as data-driven analysis of geometry. Applicants should have a strong background in geometry processing, computer vision, machine learning, and applied mathematics

Information Fusion Performance Evaluation

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Information Fusion (IF) is a research area that seeks to reduce uncertainty, extend sensing and situation awareness, and refine estimates based on data, feature, and decision association and correlation. IF has been applied to many domains; but still requires methods of comparative analysis, unique situations for multi-INT coordination, and novel mathematics in algorithm development for complex systems that integrate sensing and user interaction for timely processing and exploitation. Our challenge is to develop the necessary insights and identify the best practices to help foster and accelerate scientific discovery vital for developing affordable IF systems with predictable measures of performance for sensor resource management. A candidate set of problems includes and is not limited to the following list: 1) challenging IF problems in wide area persistent surveillance; activity analysis in complex multi-dimensional spatio-temporal data-sets, and tactical sensing situations; 2) advanced scientific image and textual analysis and knowledge discovery techniques on scalable large data sources; 3) methods of physics-based and human-based sensor fusion using multiscale (e.g. signal processing, machine-learning, and information management) algorithms in the context of anticipative computing; 4) design of experiments for performance analysis over practical and explorative scientific studies; and, 5) any topic of relevance to Air Force mission involving application science, large scale computing, precision and performance metrics driven operational (e.g. sensor, target, and environment) constraints.

Fusion of Physics-Derived and Human-Derived Data

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Techniques for physics-derived applications are prevalent such as simultaneous tracking and classification/identification and sensor exploitation. Likewise, efforts from natural language processing have enabled text extraction. Currently, there is a need to combine various intelligent data sources towards a combined physics-based and human-derived information fusion solution. The technical challenge is to understand and model the association between these sources of information, combined with the algorithms that extract and exploit information towards a robust

solution. The performance evaluation of these efforts require understanding of the data, metrics, and usefulness of how, when, and where to best combine the methods. We are interested in the theoretical and practical problems over scenarios that provide situation assessment, awareness and understanding over different sensors, targets, and environments. The scope of the inputs include: video, text, voice, and scanned archives for air, space, and cyber activities. Developments for situation awareness (e.g., The Data Fusion Information Group Model of Level 2 Fusion "Situation Assessment"), include entity, event, and group behavior modeling, measurement, and performance analysis from which novel solutions are sought.

Enhanced Exploitation and Analysis Tools

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Research in data, sensor, and information fusion supports numerous applications; however, the ability of techniques and tools to support operational needs is based on user attributes (e.g., The Data Fusion Information Group Model of Level 5 Fusion "User Refinement"). A current need is to understand how different tools such as target trackers, semantic extraction engines, and data exploitation methods support users. Research questions include advanced computing, analytics, security, data visualization, and human-machine interaction. Various applications such as full motion video (FMV), hyperspectral imaging (HSI), high-range resolution radar (HRR), satellite imagery, wide area motion imagery (WAMI), text, and Open Source Intelligence (OSINT) require different techniques to balance user interaction and machine exploitation. The technical challenge is to achieve a robust balance between computational effort, timeliness, and performance between databases, users and exploitation tools. We are interested in the academic and application problems that bridge the balance for unstructured scene perception, semantic understanding, and data control over multiple spatial, temporal, and frequency scales. The detection, characterization, and learning of patterns that impact exploitation, tracking, prediction, and validation of potential targets for activity-based intelligence will be of interest. Various analytical and practical tools that capture autonomous decision making, build assistive tools, and facilitate reporting will be considered.

Programming for Emerging Nonlinear Computer Architectures

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Modern computer architectures are separated into multiple abstraction layers: hardware, firmware, operating system, middleware, applications, etc. In this organization, low level details are abstracted away from higher level users. For instance, application programmers can focus on

designing and implementing new algorithms and functionality without having to worry about the intimate details of instruction set architectures, physical memory management, communications protocols, etc. While this organization has been great for implementing everyday applications, the abstraction layers have actually been a hindrance for specialized applications. In order to attain high algorithmic efficiency, scientific computing practitioners must understand the details of available instruction sets (e.g., MMX and SSE), pipelining, cache design and memory bus bandwidth, amongst others. Similarly, security implementers must be cognizant of any special hardware (e.g., TPM chips and AES-NI extensions) to attain high performance and security. The same applies to nonlinear computing as well. In other words, the abstraction layers do not exist for these specialized applications and neither do their benefits.

However, as performance and security have become mainstream problems, new middleware and programming paradigms have been introduced. For example CUDA and OpenCL are two new programming paradigms that help abstract away some of the details of stream programming. Users write code in a C like language, and the compiler takes care of data organization and stream processor allocation. Hadoop is another example of a middleware that abstracts away the details of parallel and distributed programming and exposes the much simplified map-reduce algorithm.

This topic seeks to research and develop techniques and tools for abstracting away the details of a nonlinear computing system. An example topic of interest is compilers or middleware that abstract away the dynamic nature of chaos computers. In this way, if chaos computing is used for code obfuscation, the compiler is, in essence, a program obfuscator. A second example is model based design and implementation for nonlinear computing components. In this example topic, the different nonlinear computing instantiations are formally modeled. These models are then used to compose applications and runtime code that abide by user specifications.

Towards Precise Low Level Program Analysis

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Program analysis has traditionally been separated into two categories – dynamic and static. In dynamic analysis the sample under test is executed and its runtime behavior is analyzed. In static analysis, the sample is analyzed at rest. The main benefit of static analysis is code coverage, (e.g., the full control flow graph of a sample can be built) however, its main disadvantage is the lack of runtime or concrete data values. Conversely, the advantage of dynamic analysis is the availability of concrete information and the disadvantage is the lack of coverage. Thus, program analysis in practice is likely to use both static and dynamic techniques.

There are also different dimensions to program analysis. Analysis-granularity is one of them. For obvious reasons, analyzing a program at a high level representation (e.g., source code) can benefit from the available contextual information which is lost when a program is analyzed at a lower level (e.g., assembly). This loss of high level information, in turn, leads to a loss of precision (i.e., increase in false positives). Unfortunately, low level analysis is the only viable

approach for many applications. For instance, malware samples normally arrive as binaries and not as source code.

The main goal of this topic is to investigate techniques that can be used to increase the precision of low level analysis. To put it differently, how can we make low level analysis as precise possible with the upper bound being high level analysis? The proposed work should initially focus on individual sub problems in program analysis – information flow, control dependency, etc.

Nonlinear Computing Systems and Architectures

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As semiconductor technologies continue to scale further into the nanometer regime it is important to study how non-traditional computer architectures may be uniquely suited to take advantage of the novel behavior observed for many emerging technologies. Nonlinear computing systems represent a type of non-traditional architecture encompassing evolutionary systems where the dynamics of evolution from one operational state to another are nonlinear. An example nonlinear computing system is the chaos computer where chaotic oscillators are used as complex logic components in the construction of the overall system. Such nonlinear computing systems hold great promise for several applications including dynamic reconfigurable computing, computational intelligence, and security.

Nonlinear computing systems research requires interdisciplinary work from several diverse fields such as physics, electrical and computer engineering, computer science and from both pure and applied mathematics. Interest in this topic includes the study of models and prototypes of nonlinear computing systems in terms of a variety of performance metrics such as speed, energy consumption, accuracy and security. One particular interest is the investigation of the use of nonlinear computing systems for improved security; for example, mitigating side-channel attacks and/or providing new avenues for code obfuscation. This would include the study of potential tradeoffs between security and other performance metrics such as energy and delay. Other potential uses of nonlinear computing artifacts of interest to this research include the construction of reconfigurable computing platforms, neuromorphic systems, and new approaches to evolutionary computing, to name a few. Furthermore, from a more theoretical perspective, there is interest in developing a better understanding of the underpinnings of nonlinear systems and their relationship to complexity driven computation. Building on such theoretical work, one could also study how design choices can be used to either encourage or discourage the promotion of complexity from lower level components to higher levels of abstraction.

Secure Processing Systems

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The objective of the Secure Processing Systems topic is to develop hardware that supports maintaining control of our computing systems. Currently most commercial computing systems are built with the requirement to quickly and easily pick up new functionality. This also leaves the systems very vulnerable to picking up unwanted functionality. By adding specific features to microprocessors and limiting the software initially installed on the system we can obtain the needed functionality yet not be vulnerable to attacks which push new code to our system. Many of these techniques are known however there is little commercial demand for products that are difficult and time consuming to reprogram no matter how much security they provided. As a result the focus of this topic is selecting techniques and demonstrating them through the fabrication of a secure processor. Areas of interest include: 1) design, layout, timing and noise analysis of digital integrated circuits, 2) Implementing a trusted processor design and verifying that design, 3) Selection of security features for a microprocessor design, 4) verifying manufactured parts, and 5) demonstrations of the resulting hardware.

Edge of Chaos Computational Architectures and Cortical Networks

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Recent advancements in nanoelectronics, photonics, neuromorphic systems, and cognitive neuroscience are enabling the development of radically different computational architectures based on reservoir computing concepts. Such systems are theoretically capable of solving the toughest temporal/spatial classification and regression problems with Air Force applications focused on increased system autonomy and perception. This research explores a new class of computationally intelligent processers governed by the nonlinear dynamics within oscillating optical or electronic reservoirs. The nonlinear dynamics and delayed feedback (short term memory) of reservoirs enable networks to mimic transient neuronal responses and to project time dependent input into high dimensionalities for categorization by an outside classifier. Such hardware based reservoirs can operate near the edge of chaos providing extreme sensitivity to input variations for increased degrees of separability between input signatures. In this context, the reservoirs function as time delayed recursive networks that utilize feedback as short term dynamic memory for the processing of time-series input signals. These systems offer potentially disruptive capabilities in real time signature analysis, time-series predictions, and environmental perception for autonomous operations. Interests associated with this topic include; exploration of the required properties and associated mechanisms to build efficient reservoirs, system modeling, spike-timing-dependent plasticity (STDP), and cortical architectures, with emphasis on bio-inspired computational schemes based on the physics of near chaotic systems.

Advanced Event Detection and Specification in Streaming Video

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Video is leveraged for a variety of monitoring tasks, ranging from the monitoring of bridges, traffic and the interior of large buildings, to providing situational awareness in real time via unmanned aircraft. Presently such systems need to be monitored by human operators who must maintain high levels of constant vigilance to search for critical events that occur infrequently. The goal is to develop algorithms that operate in real time (or near real time) that can detect and characterize both short-term events (recognized in a single or few consecutive frames of video) and/or long-term activities (composed of one or more correlated events). Also of interest are enabling technologies and techniques; to include the specification of events via high level query languages, query optimization, multi-INT data fusion (e.g. to include combining multiple modalities of data into a stream amenable to off-line search and retrieval or subsequent processing in a cloud computing environment). Architectures of interest include both CPU and GPU, as well as cloud/distributed systems and mobile devices.